



Comparative Analysis of Concrete Mix Designs Considering Aggregate Shape on Workability & Compressive Strength

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Abstract: Aggregate shape is an important factor for concrete performance, but most existing studies have focused on idealized single-shape aggregate rather than mixed-shape aggregate compositions that are common in practice. The present work is an experimental investigation on the influence of coarse aggregate shape composition, individual and systematic blends on workability and compressive strength of M25 grade concrete. Particle characterization was carried out by sieve analysis, flakiness and elongation index tests and by visual inspection. Based on the characterization, eight mixes were prepared with different proportions of flaky, elongated, angular and irregular coarse aggregates at a constant water cement ratio of 0.67. Workability was determined by the slump test (ASTM C143/C143M) and compressive strength was determined at 7- and 28-days using cube specimens tested according to BS EN 12390-3. The results showed that the workability varied significantly with slump ranging from 99 mm to 152 mm and 28-day compressive strength from 24.45 N/mm² to 35.58 N/mm². The 100% angular mix achieved the highest compressive strength (35.58 N/mm²) while the 100% irregular mix achieved the highest slump (152 mm) and adequate strength (32.84 N/mm²). A flaky-dominant blend was the only mix that failed to meet the minimum characteristic strength requirement. Among the blended compositions, the blend of 60% angular and 25% irregular, with only 15% of flaky and elongated aggregates gave the best overall balance of workability (131 mm) and strength (32.07 N/mm²). The results show that predominantly angular blend with irregular fractions yields the most consistent performance for M25 grade structural concrete, offering useful insights for aggregate selection and mix design.

Index Terms: aggregate shape, angular aggregates, compressive strength, elongated aggregates, flaky aggregates, irregular aggregates, workability

1 INTRODUCTION

Concrete, a fundamental material in construction, derives its properties from a complex interaction of its constituents, primarily cement, water, and aggregates. Among these, aggregates typically constitute about 60–75% per volume of any concrete mix [1], significantly influencing the mechanical properties and the workability of concrete. The properties, such as size, grading, shape and surface texture, have marked influence on workability and compressive strength of concrete [2]. Among the various aggregate characteristics, particle shape plays a significant role in concrete performance. Aggregate particles exhibit a range of morphologies, including rounded, angular, flaky, and elongated forms [3]. Due to natural weathering, extraction methods, and mechanical crushing, a single aggregate inherently contains a mixture of shapes. Well-shaped aggregates, typically those with rounded forms, tend to enhance the workability of concrete by reducing internal friction and facilitating smoother mixing and placement [4]. Conversely, irregularly shaped or elongated aggregates can lead to increased friction and resistance and higher water demand, making the concrete mix more difficult to handle and compact [5]. Aggregate shape plays a significant role in concrete performance by influencing particle packing density, void content, inter-particle friction, and the characteristics of the aggregate–cement paste interfacial transition zone (ITZ) [2], [6], [7]. Previous studies have confirmed that aggregate shape affects the workability and mechanical properties of concrete. In practice, coarse aggregates consist of mixtures of particles with different shapes than individual particle morphology. Limited research has systematically compared the performance of concrete produced with mixed-shape compositions under similar mix design conditions. As a result, the influence of the dominant aggregate shape composition on workability and compressive strength is not sufficiently understood. Moreover, with the increasing demand for sustainable construction practices, the industry faces additional pressure to utilize locally available aggregates, which vary widely in shape and texture. Understanding the relationship between aggregate shape, workability, and compressive strength can thus enable more efficient use of resources, reduce construction costs, and enhance the durability and safety of concrete structures.

This study aims evaluating both individual aggregate shapes and systematically designed dominant-shape mixtures within a single experimental framework. By maintaining a constant concrete mix design while varying only the proportions of flaky, elongated, angular, and irregular coarse aggregates, the study denotes the effect of aggregate shape composition on the workability of fresh concrete and the compressive strength of hardened concrete.

2 RELATED WORK

2.1 Aggregate Shape Characterization and Classification

Aggregate shape is often categorized by particle geometry into rounded, irregularly shaped, angular, flaky and elongated forms, with visual inspection together with flakiness and elongation indices being commonly used classification tools in practice [8], [9]. Hu and Stroeven [10] proposed image-analysis-based descriptors to quantify particle shape. Their research demonstrated that shape determines the packing density of aggregate and thus the microstructure of the interfacial transition zone (ITZ) between aggregate and cement paste. The shape is strongly affected by the parent rock type, extraction method and crushing process, and hence, a single pure form is rarely found in aggregate stockpiles, and batches are typically a mixture of differently shaped particles [8]. This natural variability has led to the development of standardized shape indices, but most subsequent performance studies still test individual, idealized shape categories in isolation, not realistic mixed compositions.

2.2 Effect of Aggregate Shape on Workability of Fresh Concrete

Workability, most commonly measured through the slump test as summarized by Koehler and Fowler [11] among more than sixty available test methods for concrete, is highly sensitive to aggregate particle shape. Abdullahi [14] compared quartzite, granite, and river gravel aggregates and found that the rounded, smooth-surfaced river gravel produced the highest slump, since rounded particles offer lower inter-particle friction than angular ones. Similarly, Molugaram et al. [6] reported that flaky and elongated particles increase the specific surface area of the aggregate, raising cement paste demand and reducing workability, whereas well-rounded particles improve flow. The study conducted by Kaplan & Meier, [16] has further elaborated that changes in the angularity of coarse aggregates have a greater effect on the workability of concrete than changes in the flakiness of the aggregates. Neville and Brooks, (2010) as cited in Oluwasola et al. [14] elaborated on this by noting that, by virtue of the spherical aggregate surface area being less and the reduced interparticle friction, workability is better for concretes produced with spherical aggregates than concretes produced with other aggregate types. They concluded that irregular shape and rougher texture of angular aggregate demand more water than spherical aggregations. Overall, these studies show that, in general, rounded aggregates increase workability while angular, flaky, elongated and irregular aggregates decrease workability by increasing internal friction and demand for cement paste and mixing water.

2.3 Effect of Aggregate Shape on Compressive Strength of Concrete

The effect of aggregate shape on compressive strength is usually due to mechanical interlocking and the quality of bond at the aggregate-paste interface. Konitufe et al. [15] compared the angular and rounded coarse aggregates in six sizes and found that the angular aggregates consistently showed higher 28-day compressive strengths compared to rounded aggregates. The increase was attributed to better interlocking and a rougher surface that bonds better with the cement paste. A similar trend was reported by Palcis [16] who stated that angular aggregate particles with sharp edges increase packing density & mechanical keying compared with smooth, rounded aggregates. On the other hand, Molugaram et al. [6] also reported that flaky and elongated particles are poorly workable and do not necessarily increase the concrete strength, but tend to break during compaction and orient horizontally within the matrix, which can reduce the compressive and flexural strength. The concept was validated numerically by Naderi et al. [17] using a mesoscale finite element model. They found that angular aggregates get strength from rougher surfaces that bond better with the matrix, and from higher aggregate strength, convexity and angularity, and lower elongation. Overall, the literature indicates a consistent trade-off, with angular, interlocking particles favoring strength and rounded particles favoring workability. Irregular aggregates are often proposed as a practical compromise. Few studies however quantify this trade-off with systematically blended shape proportions, rather than single, idealized aggregate types.

3 METHODOLOGY

An experimental study was conducted to assess the effect of coarse aggregate shape composition on the workability of fresh concrete and compressive strength of hardened concrete. Portland cement, locally available river sand as fine aggregate, potable water and crushed coarse aggregates were used throughout the study. Before preparing the mixture, the coarse aggregates were characterized by particle size distribution using 28 mm, 20 mm and 14 mm sieves. The aggregates were then classified into four shape groups; flaky, elongated, angular and irregular, using visual inspection and flakiness and elongation index tests.

3.1 Materials

Cement – In this research 42.5N/R grade Portland-composite cement. All possible contact with moisture is avoided during cement storage.

Fine Aggregate - Locally accessible river sand passed through a 4.75 mm IS sieve is used as fine aggregate. Before it is used, the sand is thoroughly cleaned, washed, and filtered to remove impurities.

Coarse Aggregate - A total of 250 kg of crushed coarse aggregates were provided for this analysis.

3.2 Materials

Before conducting the flakiness and elongation tests, as well as the visual inspection, a particle distribution test was performed on the coarse aggregates to characterize the materials. A total of 250 kg of coarse aggregates were used for this analysis. The aggregates were sieved using 28 mm, 20 mm, and 14 mm sieves to separate them into different-size fractions (Fig. 1.). Once the sieving process was completed, the aggregates were grouped based on their size and prepared for the subsequent tests. The flakiness test was conducted to identify the aggregates that had a thin, flat, while the elongation test was used to determine the aggregates with an elongated, needle-like form (Fig. 2.). Additionally, a visual inspection was carried out to further classify the aggregates. The visual inspection allowed for the recognition of angular aggregates, characterized by their sharp, well-defined edges and corners, along with rough surface textures and a blocky, fragmented appearance [11], as well as irregular aggregates, which have a more rounded or mixed shape. From this process, flaky aggregates, elongated aggregates, angular aggregates, and irregular aggregates were identified.



Fig. 1. Sieve Analysis of Coarse Aggregates



Fig. 2. Performing flakiness index test

3.3 Mix Proportions and Experimental Factors

The mix design of concrete involves selecting the necessary ingredients and determining their relative proportions to create a concrete mixture that is both economical and meets specific strength and durability requirements. This process is essential to ensure that the final concrete product is suitable for its intended use. The mix proportion of coarse aggregates categorized by shape are presented in the Table 1.

Table 1. Mix proportion percentages

	Flaky	Elongated	Angular	Irregular
Sample 1	100%	0%	0%	0%
Sample 2	0%	100%	0%	0%
Sample 3	0%	0%	100%	0%
Sample 4	0%	0%	0%	100%
Sample 5	60%	25%	10%	5%
Sample 6	5%	60%	25%	10%
Sample 7	10%	5%	60%	25%
Sample 8	25%	10%	5%	60%

3.4 Casting of Concrete Cubes

Mix design is carried out to form M25 grade of concrete for the test. The ingredients for different concrete mixes were weigh-batched and then thoroughly mixed using a concrete mixer with water cement ration of 0.67. The mixed concrete was then poured into cubic moulds of standard size 150 mm x 150 mm x 150 mm (Fig. 3. & Fig. 4.). Before pouring the concrete, the moulds were properly cleaned and coated with oil to ensure easy removal later. All the materials were mixed in their dry state, and subsequently, water was added to the mixture, ensuring it was mixed well. Two concrete cubes were cast per sample to ensure the accuracy of the test results.



Fig. 3. Labelled Concrete Cubes



Fig. 4. Casting Concrete Cubes

3.5 Curing Process

Water curing was carried out for 7 days and 28 days after the specimens were removed from the moulds. After 24 hours of casting, all the samples were demoulded and placed in the tank filled with clean and portable water. Fig. 5. shows the curing process of demoulded concrete samples for the 7-day and 28-day compressive strength tests.



Fig. 5. Curing Concrete Cubes

4 EXPERIMENTS

Two main experiments were carried on 8 concrete samples. The slump test was performed for freshly mixed concrete to check the workability while the compressive strength test was carried out on hardened concrete cube specimens to check the maximum amount of compressive load a material can bear before fracturing.

4.1 Compressive Strength Test

The compressive strength of the concrete was determined using a compression testing equipment (Fig. 6.) in accordance with BS EN 12390-3 as shown in Fig. 7. This test involves applying a standard load parallel to the longitudinal axis of pre-moulded and thoroughly cured concrete cubes. Before testing, each specimen was removed from the curing tank and allowed to dry on the surface. The specimen was then carefully centered on the lower bearing plate of the compression testing machine to ensure uniform load distribution. A compressive load was continuously and uniformly applied along the longitudinal axis of the specimen at a constant rate until failure occurred. The maximum load sustained by the specimen at failure was recorded, and the compressive strength was calculated using the following equation:

$$\text{Compressive strength (MPa)} = \text{Maximum load at failure (N)} / \text{Cross-sectional area (mm}^2\text{)} \quad (1)$$



Fig. 6. Compressive Strength Testing Machine



Fig. 7. Tested Concrete Cubes

4.2 Workability Test (Slump Test)

The workability of fresh concrete was assessed using the slump test in accordance with ASTM C143/C143M (Fig. 9). The slump value was determined by measuring the difference in height between the top of the mold and the highest point of the settled concrete specimen as shown in the Fig. 8.



Fig. 8. Measuring slump values



Fig. 9. Performing Slump test

5 RESULTS AND DISCUSSION

Workability – The slump values recorded for each sample are mentioned in the Table 2. Overall the slump value ranging from 99 mm to 152 mm depicts a noticeable variation in workability directly associated with the shape of coarse aggregates used. The Sample 1 and Sample 2 which contain 100% of flaky and elongated coarse aggregates show a comparatively lowest slump values showing low workability. This result is in line with the established findings in the literature. In contrast, the Sample 3 and Sample 4 shows the highest slump values of 148 mm and 152 mm respectively, representing a significant improvement in workability as compared to the flaky and elongated dominant mixes. The sample 03, which consisted with 100% of well graded angular coarse aggregates facilitated better particle packing and reduced void content hence resulting a higher of the slump value. A comparable outcome was observed in the Sample 4, which is fully consisted of irregular coarse aggregates. Moreover, the combined effect of angular and irregular aggregates is represented by the sample 7, dominated by 60% of angular aggregates and 25% of irregular aggregates, which records a slump value of 131 mm. The sample 8 shows the next highest slump value of 122 mm. The sample 8 comprises of 60% of irregular shaped aggregates, along with 25% of flaky content, 10% of elongated content and only 5% of angular aggregates contributed to a lower the workability than sample 7. Sample 5 and sample 6 denote a closely comparable slump values and in both the samples, the flaky and elongated aggregate proportions are dominant. However, sample 6 exhibits slightly higher workability than sample 5, which may be attributed to its higher proportions of angular and irregular aggregates more than of sample 05.

Table 2. Results of Slump cone test

Sample Name	Slump Value (mm)
Sample 1	99
Sample 2	101
Sample 3	148
Sample 4	152
Sample 5	117
Sample 6	119
Sample 7	131
Sample 8	122

Compressive strength – The compressive strength test results of each sample are shown in the Table 3 (Fig. 10.). The target means strength for M25 concrete was 31.56 N/mm² and the minimum characteristic strength was 25 N/mm². All samples exhibited an increase in the compressive strength between 7 and 28 days, consistent with progressive hydration of cement overtime. Based on the results it is evident that, the rate of strength gain varied across the samples depending on the aggregate shape characteristics. According to the results, the greatest compressive strength 35.58 N/mm² is recorded in Sample 3, which contain 100% of angular shape coarse aggregates. The 28-day compressive strength recorded by Sample 3 is greater than the target means strength. The strength has gained by 12.39 N/mm² from 7 days of curing to 28 days of curing. In contrast, the Sample 5 which is flaky dominant, has recorded the lowest strength gain, increasing from 18.19 N/mm² to 24.45 N/mm²; that is 6.26 N/mm². In addition to that, Sample 1 which is entirely composed of flaky aggregates shows the lowest 28-day compressive strength among single aggregate shape mixes at 28.93 N/mm². The 28-day compressive strength of Sample 2 which contains 100% of elongated coarse aggregates is greater than the Sample 1 showing that the effect of elongated aggregates on the characteristic compressive strength of concrete more significant than that of flaky aggregates. Nevertheless, the compressive strength of both samples is less than the target means strength, further highlighting the structural risk associated with elongated and flaky aggregates proportion in concrete mixes. A notable lower value in strength which is less than the characteristic strength is shown by the combination of 60% of flaky, 25% of elongated, 10% of angular and only 5 % of irregular coarse aggregates in Sample 5. According to the results, concrete containing a combination of different aggregate shapes with flaky aggregates as the dominant component exhibited lower compressive strength than concrete composed entirely of flaky and elongated aggregates. This is of great practical significance as it shows that concrete mixes with high combined percentages of flaky and elongated aggregates are not suitable for M25 grade applications and should be avoided in the production of structural concrete. The 28-day compressive strength of Sample 6 and Sample 8 closely comparable at 30.7 N/mm² and 30.84 N/mm², however, the strength gain from 7th day to 28th day is lower in Sample 6 with compared to Sample 8. The Sample 6 is dominated by elongated aggregates while sample 8 is dominated by irregular aggregates. However, the 28-day strengths in both samples are less than the target means strength of 31.56 N/mm². The strength gains and the strength value of Sample 7 further elaborates that the angular coarse aggregates have a positive effect on the compressive strength on the concrete. In addition to that, the results of Sample 4 depict that irregular aggregates also can achieve target mean strength for M25 grade concrete.

Table 3. Results of Compressive strength test

Sample No	07 Days of curing		28 Days of curing	
	Maximum load (kN)	Maximum strength (MPa)	Maximum load (kN)	Maximum strength (MPa)
Sample 1	529.7550	20.4835	748.2155	28.9310
Sample 2	559.6865	21.6415	774.5005	29.9470
Sample 3	599.6816	23.1880	920.1140	35.5780
Sample 4	570.9485	22.0765	849.1855	32.8355
Sample 5	470.4155	18.1895	632.1980	24.4450
Sample 6	480.4215	18.5765	793.9675	30.7000
Sample 7	584.8635	22.615	829.4965	32.0740
Sample 8	545.4645	21.076	797.6210	30.8415

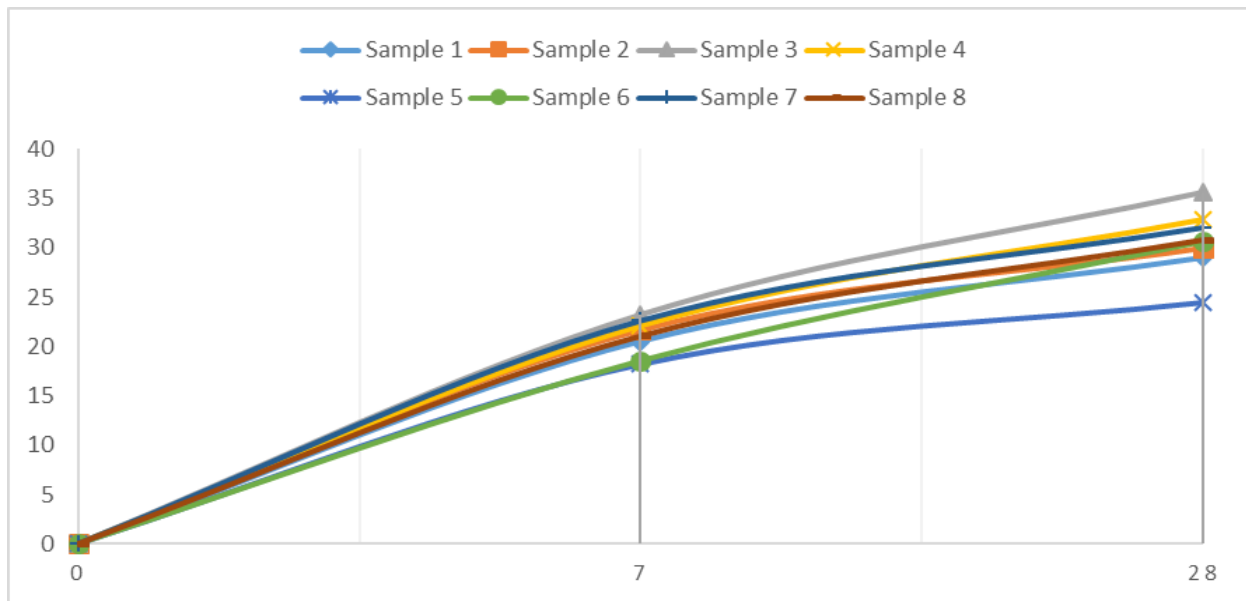


Fig. 10. Compressive Strength pattern

6 CONCLUSION

The present work aims at studying the effect of shape of coarse aggregate on workability and compressive strength of M25 grade concrete by preparing eight mixes with different proportions of flaky, elongated, angular and irregular aggregates at a constant water cement ratio of 0.67. The results indicated that the aggregate shape is an important factor affecting the properties of fresh and hardened concrete. The mixes containing 100% irregular aggregates (Sample 4, slump 152 mm, 32.84 N/mm²) and 100% angular aggregates (Sample 3, slump 148 mm, 35.58 N/mm²) showed the highest workability and the highest compressive strength respectively, both exceeding the target mean strength of 31.56 N/mm². The flaky-dominant mix (Sample 5) was the only mix to fail the minimum characteristic strength of 25 N/mm², recording only 24.45 N/mm², confirming that high combined proportions of flaky and elongated aggregates are structurally unsuitable for M25 grade concrete. Notably, the study observed that optimizing aggregate shape can simultaneously enhance both workability and compressive strength, since both properties were governed solely by aggregate shape. Sample 7 (60% angular, 25% irregular) was found to have the best overall performance amongst the mixed composition mixes with a slump of 131 mm and a strength of

32.07 N/mm² which is above the target mean strength. The results confirm the necessity of systematic characterization and optimization of coarse aggregate shape in concrete mix design and recommend a balanced combination of angular and irregular aggregates for reliable production of M25 grade structural concrete.

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